Global energy budget update

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- Review of some basics

-------------- work in progress --------------

- The energy budget and some constraints from CERES data
- Limited insights into climate sensitivity
- Confounding internal variability?

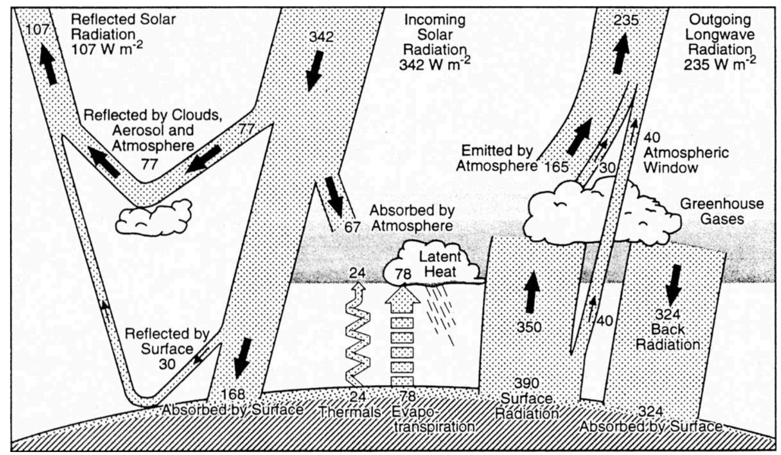
- An aside on regional contributions to the energy budget

Global energy balance

The climate energy budget rather than the vertical energy budget

In　　　Out

not



Global energy balance

The linearized climate equation:

$$\Delta N \approx F - \lambda \Delta T$$

Flux imbalance = forcing - response

Global energy balance

The linearized climate equation:

$$\Delta N \approx F - \lambda \Delta T$$

Flux imbalance = forcing - response

with the response approximated as proportional to the global average surface temperature.

Many other response terms are possible, this first-order term does rather well.

Equilibrium climate sensitivity

Relationship to equilibrium change:

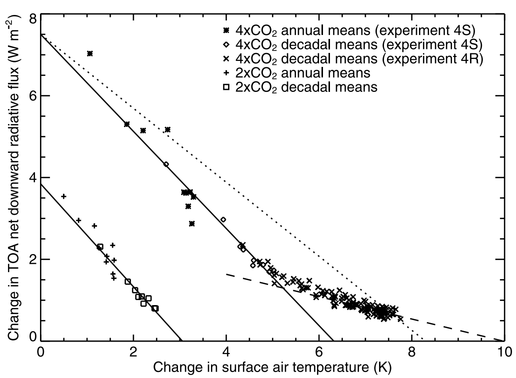
$$\Delta N \approx F - \lambda\Delta T$$

At equilibrium $\Delta N = 0$ and one can solve

$$\Delta T \approx F/\lambda$$

An important caveat is that λ is a function of the response time $\lambda(\tau)$ and also the rate of change of T.

λ estimated over 10 years does not equal λ when you give the Earth a century to respond, for example due to changes in ocean circulation and associated clouds.



Gregory et al., 2004

Equilibrium climate sensitivity

Relationship to equilibrium change:

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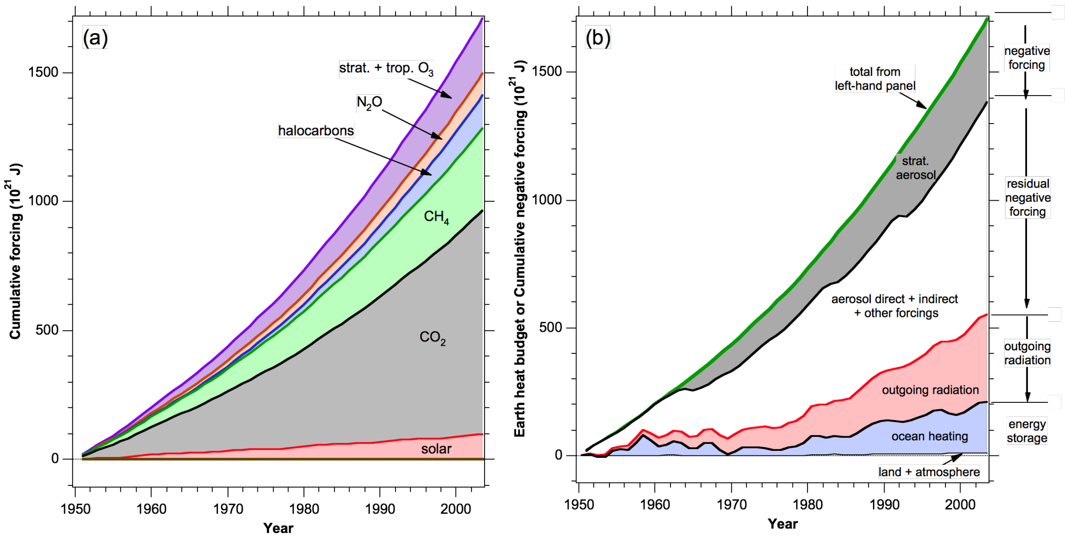
Beware of confusing terminology about ”transient climate sensitivity” .

$\Delta T_{transient} \approx F/ \lambda_{transient}$ *: the temperature change using a transient sensitivity*

$\Delta T_{transient} \approx (F-\Delta N)/ \lambda_{transient}$ *: the transient temperature change*

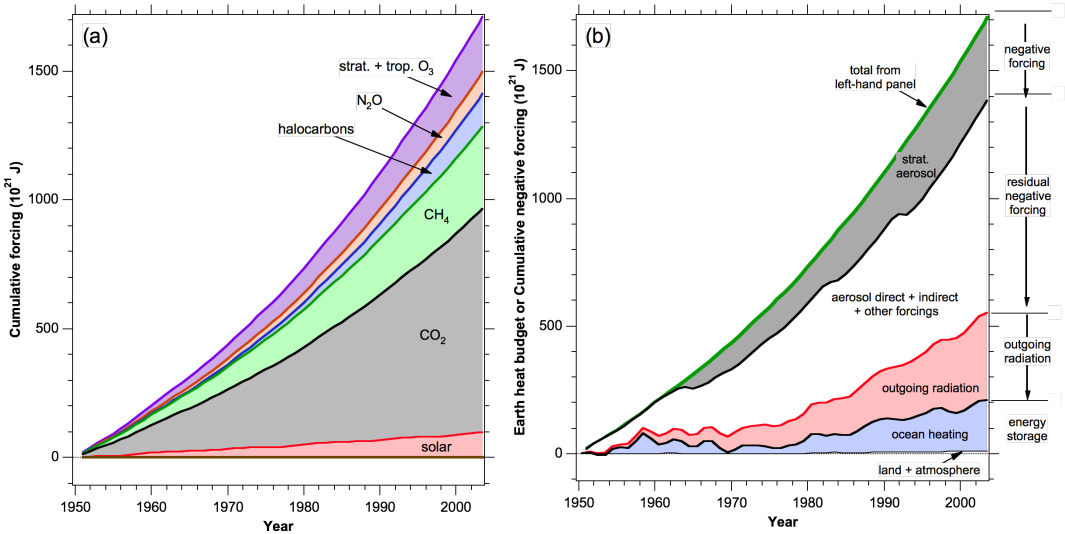
Global energy balance



Murphy et al., 2009

55e21 J boils the Great Lakes
All the coal ever burned about 15e21 J direct

Global energy balance



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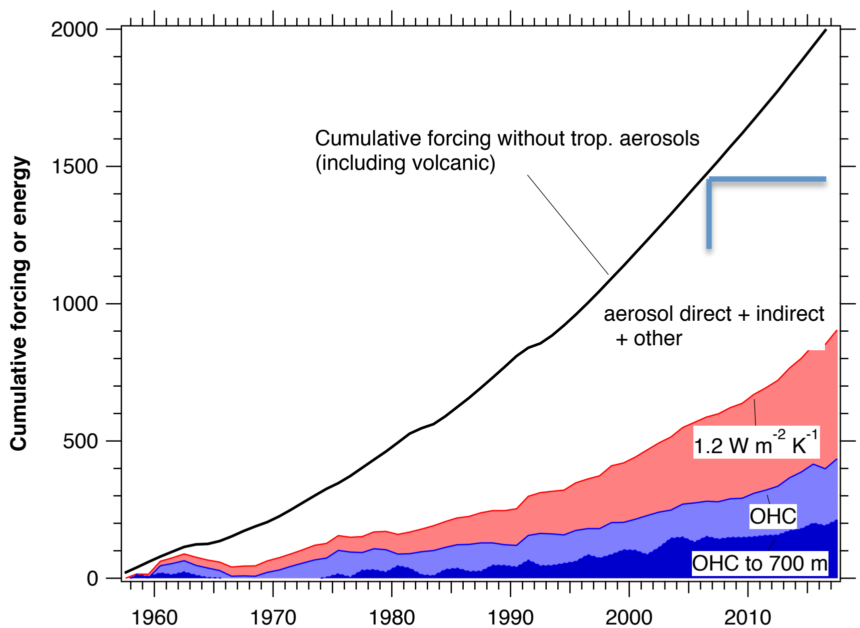
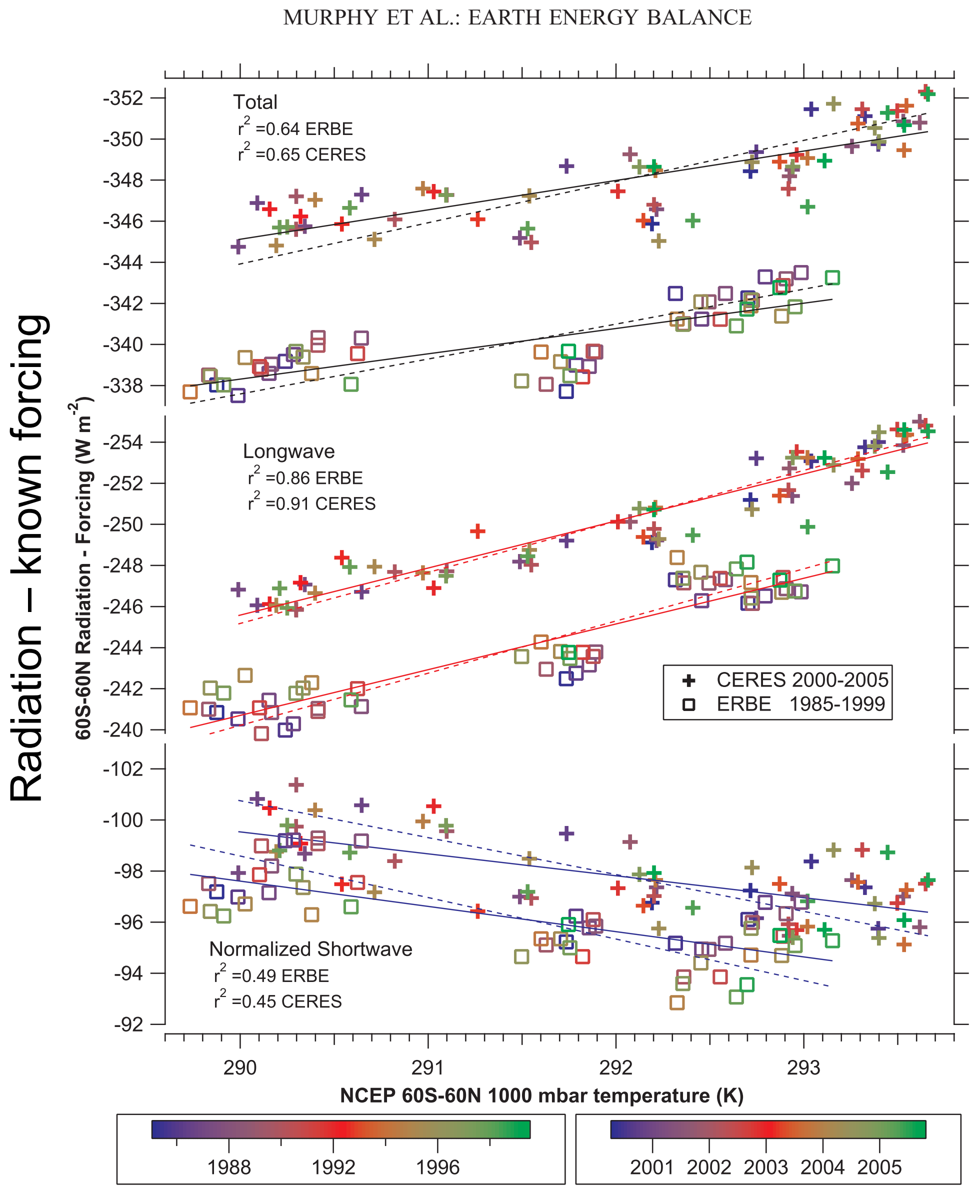
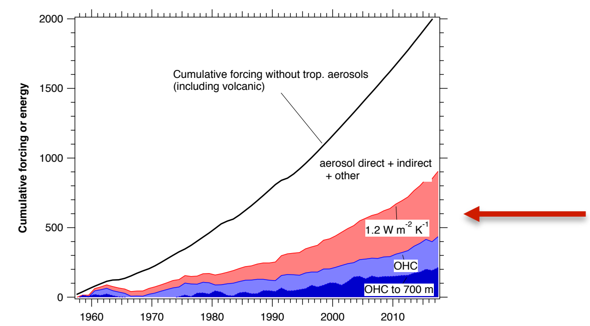


~10 years later:

had to expand the vertical scale by 40%!
otherwise, qualitatively similar

CERES data in global budget





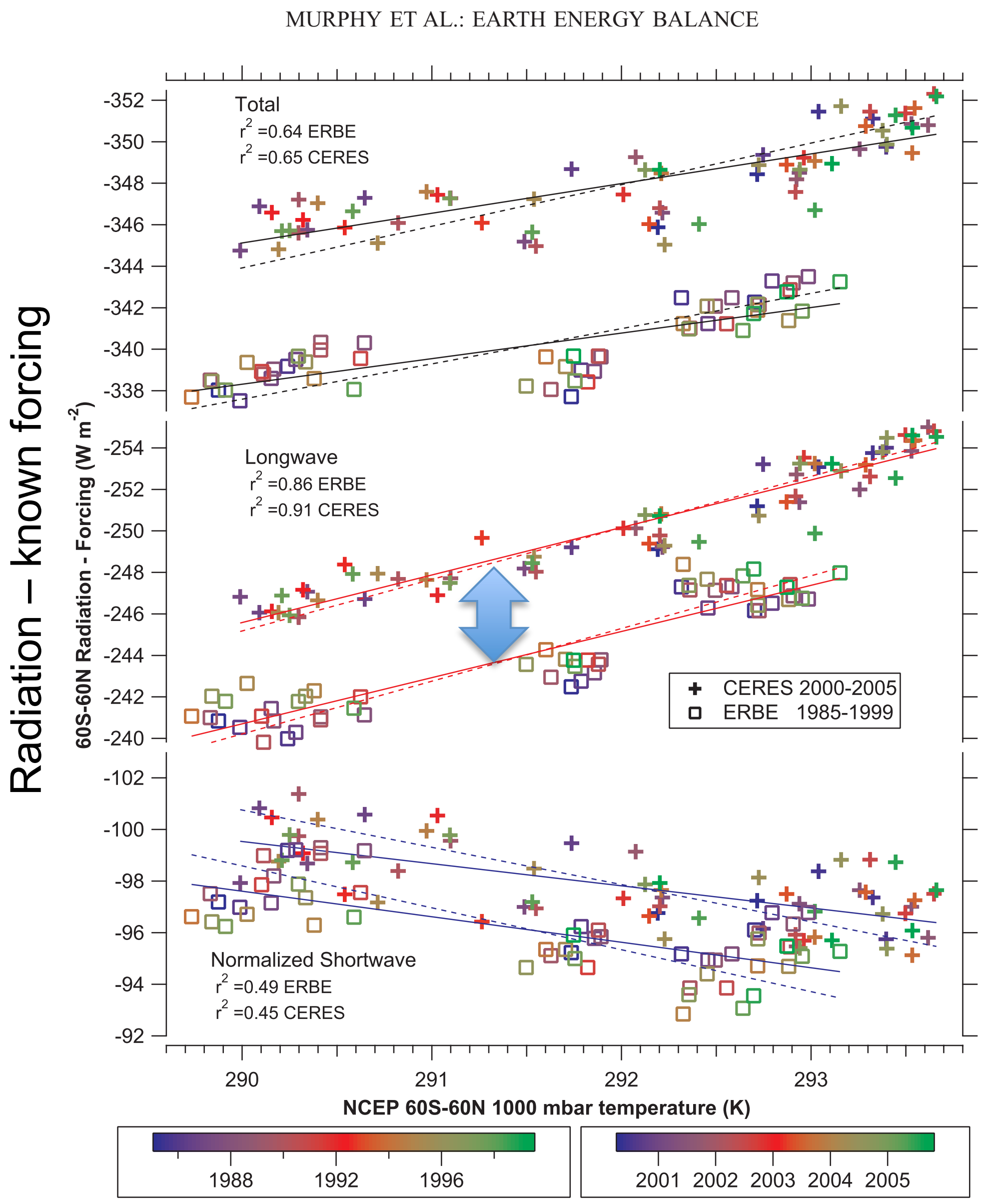
- In 2009 I tried to constrain the outgoing radiation wedge with CERES and ERBE data

$$\Delta N \approx F - \lambda \Delta T$$

$$\lambda \approx (\Delta N - F)/\Delta T$$

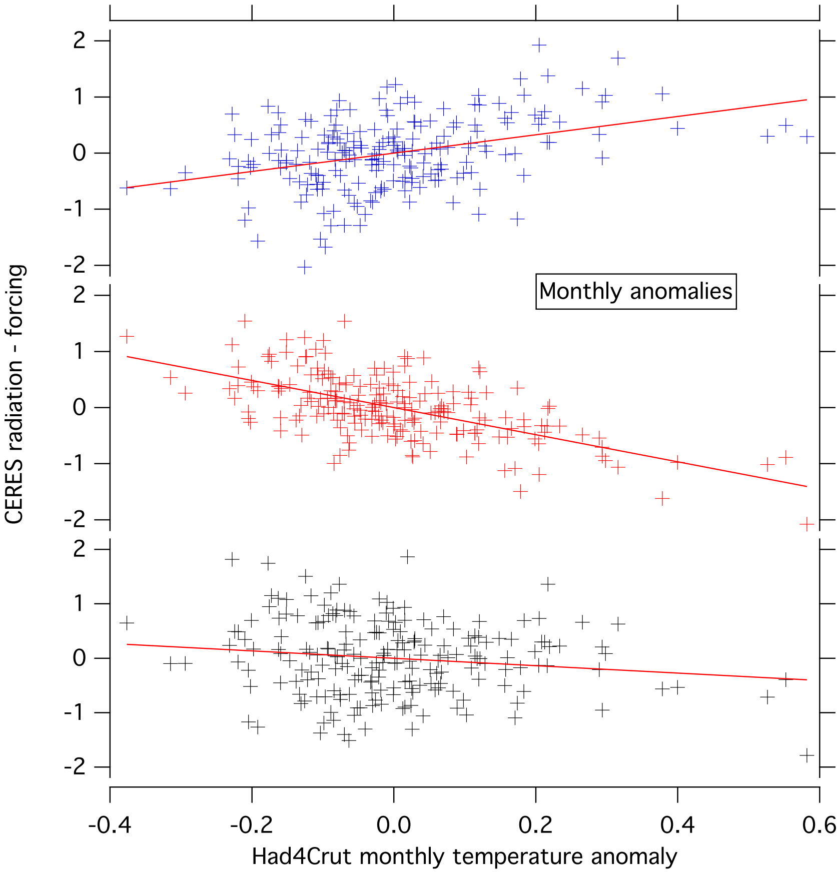
- It is very important to subtract changes in forcing
- I was always clear that this short-term λ is not λ for equilibrium temperature
- I was perhaps too optimistic in accuracy

CERES data in global budget: 2009



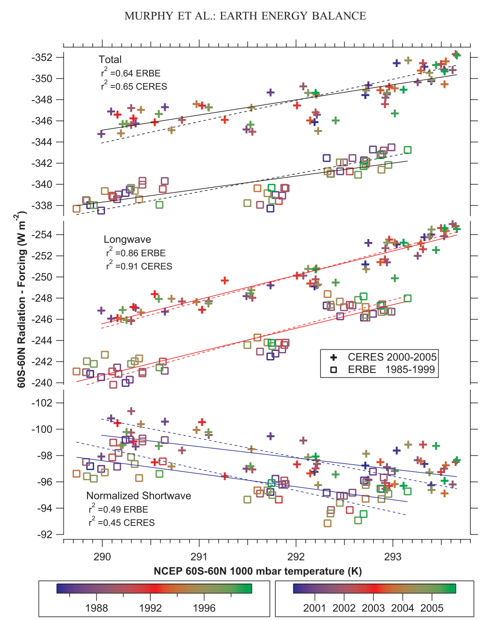
- Aside: this plot probably yields a pretty good longwave offset between CERES and ERBE
- The shortwave offset is less certain because we don't know the forcings and random cloud changes as well as longwave

CERES data in global budget: update

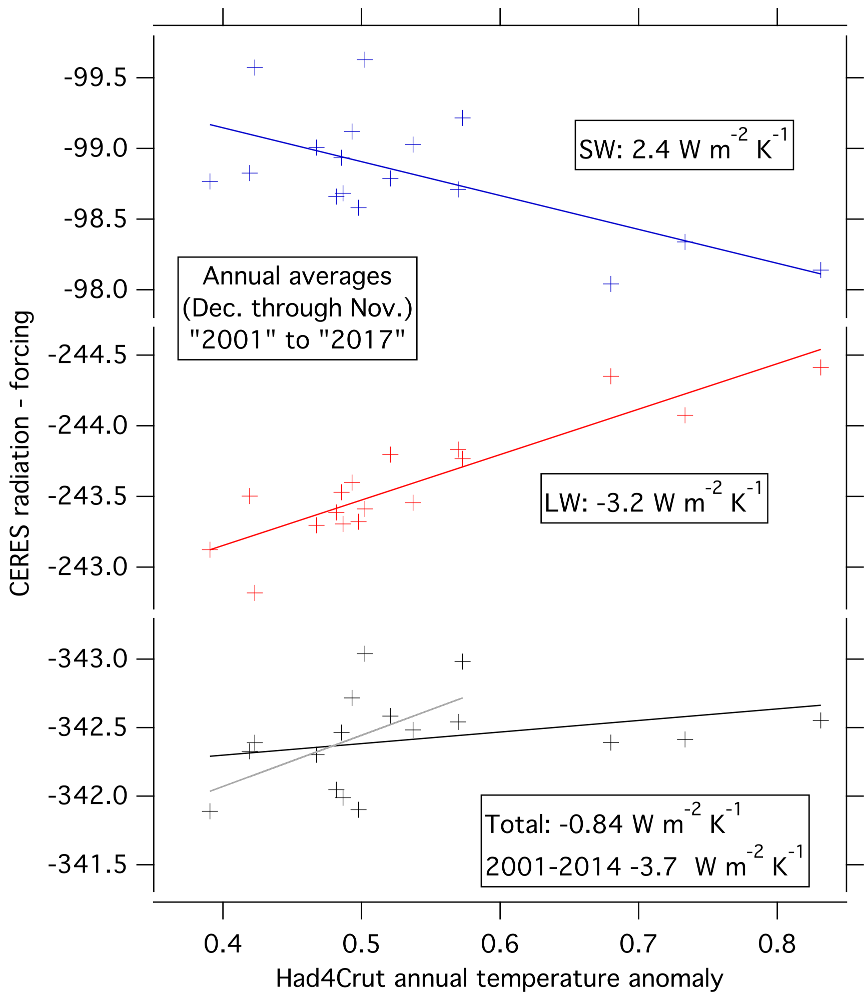


- When plotted the same way with monthly averages, slopes stay the same

longwave -2.4 versus -2.2 W m^{-2} K^{-1}
shortwave 1.7 versus 1.8

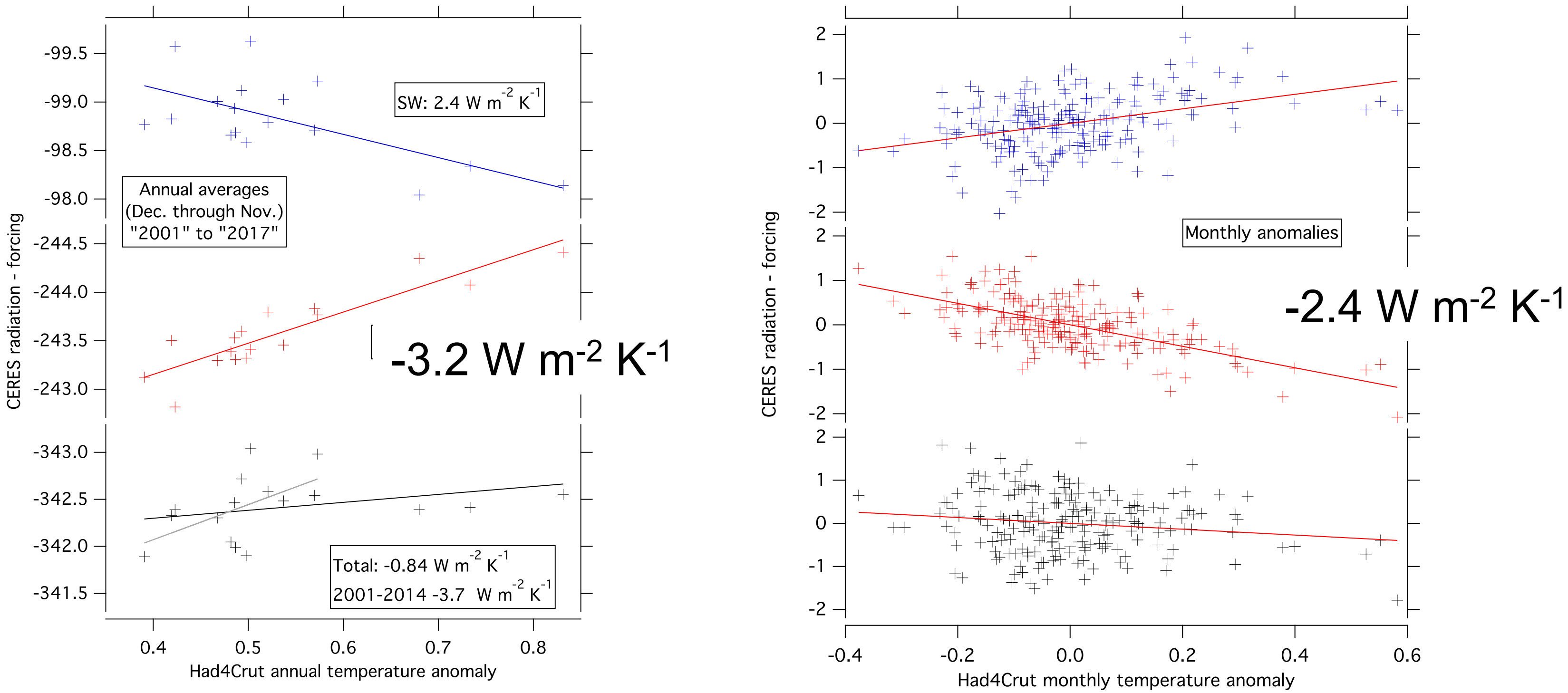


CERES data in global budget: update



- With 10 years more data we can now use annual averages.
- They should work better
- But … they yield various slopes depending on the time period
- *I think I underestimated the importance of internal variability 2016 ENSO?*
- *If we knew them, internal changes might be considered “forcing” and subtracted*
- *Subtle questions about whether anomalously warm years represent internal variability or a hint of a warmer world*

Annual or monthly anomalies

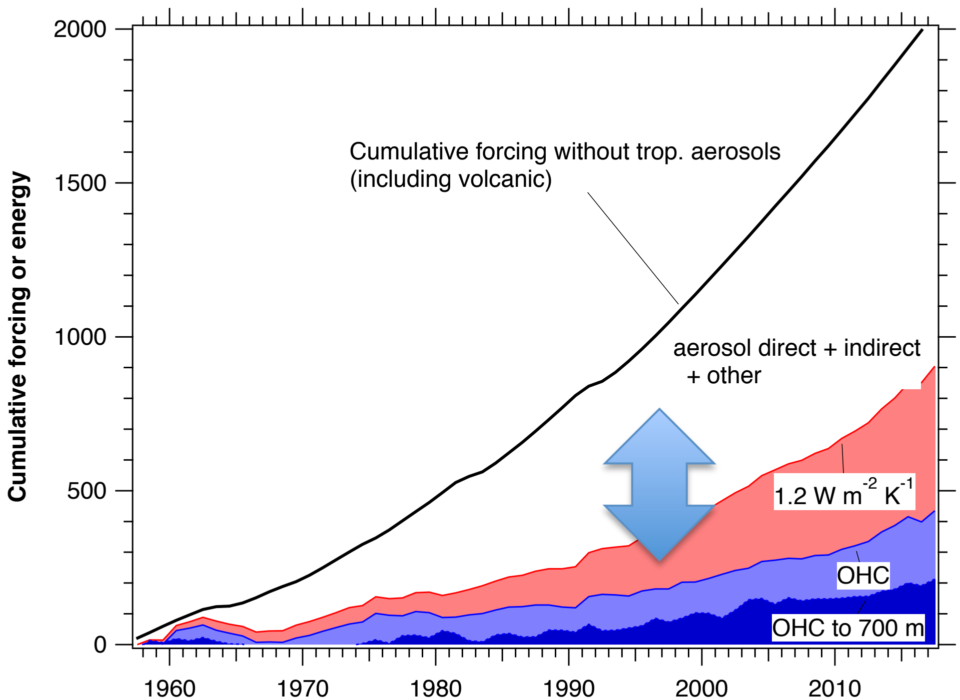


- Longwave radiative feedback should be straightforward, models are at -2.2 W m^{-2} K^{-1}
- *Why is the slope from annual averages so large?*

- *Again, questions about internal variability or a hint of a warmer world*

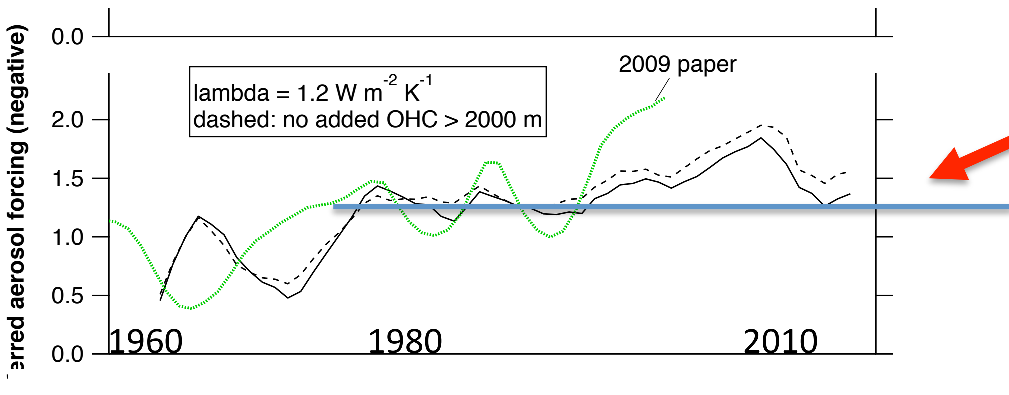
natural forcing feedback

Can we use time history to constrain climate feedback?



- Larger λ requires smaller aerosol forcing, and vice versa.
- There is no unique solution purely from energy balance.
- Look for a λ that is simultaneously plausible for the 1970s and the 2000s.

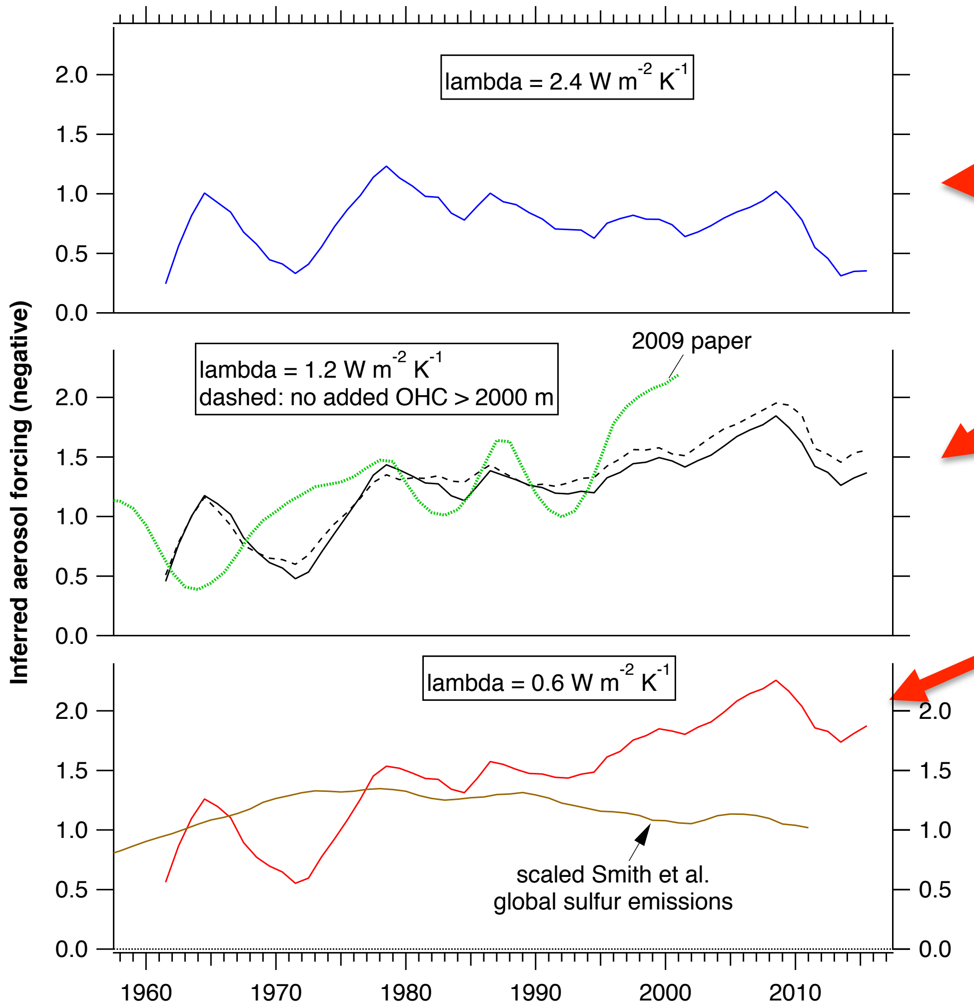
Can we use time history to constrain climate feedback?



1960 1970 1980 1990 2000 2010

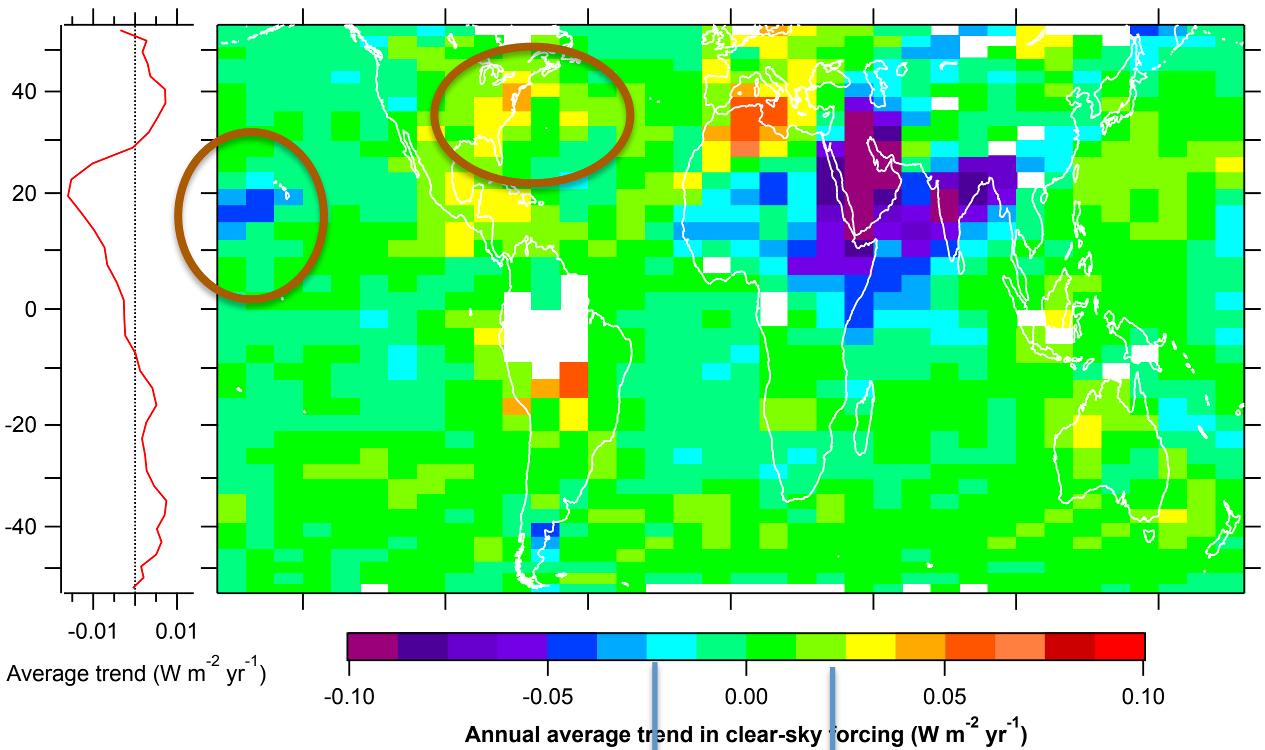
- A new ocean heat content analysis is not far off my 2009 paper with same λ
- Suggests a little over 1 W m^{-2} aerosol forcing 1980-2000
- Main result of 2009 paper
- Dashed: next slide will show that λ is far more important than uncertainties in OHC

Can we use time history to constrain climate feedback?



- λ > 2.4 requires recent aerosol forcing near zero, probably not physical
- Central estimates
- λ ≤ 0.6 implies a rapidly rising aerosol forcing, probably inconsistent with emissions.
- *Unfortunately 0.6 to 2.4 does little to narrow range in λ.*

Can we measure those aerosol forcing trends?



- MISR data with simple radiative transfer model trend 2001-2012
- Satellites can see the *regional* changes.
- **Significant changes in the *global average* are in the noise.**

Range of 0.5 W m^{-2}

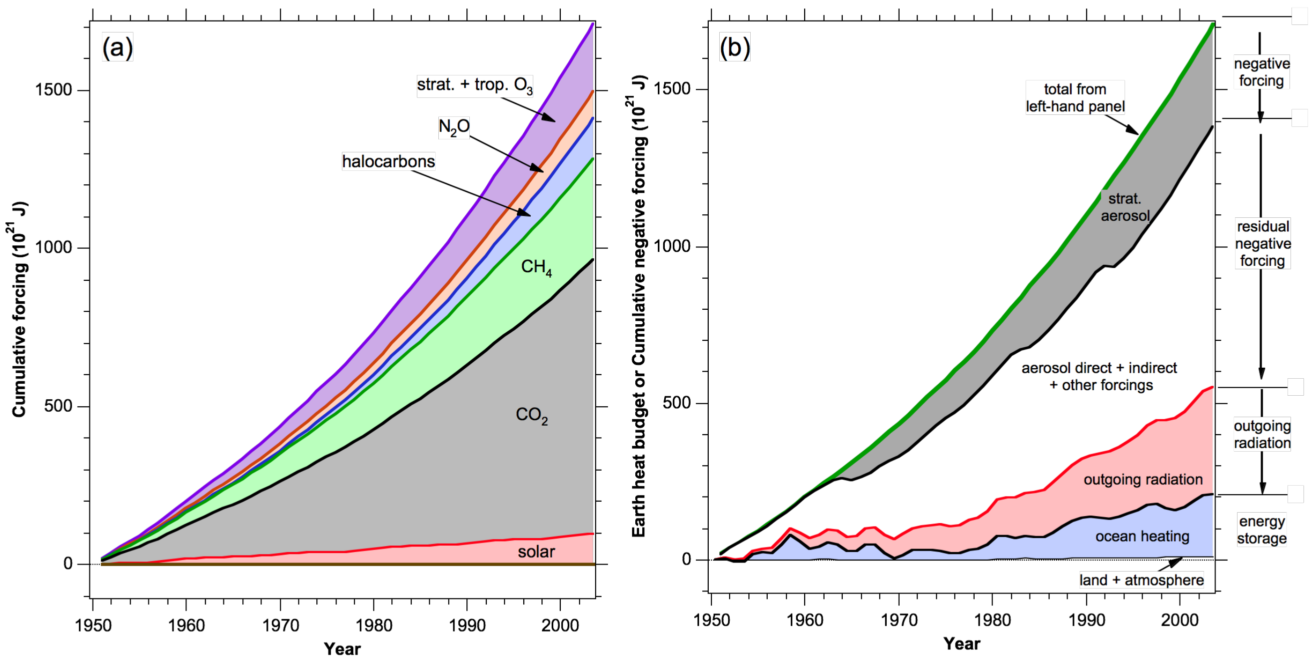
Accurate trends would require aerosol optical depth to <0.005 $decade^{-1}$

All-sky shortwave with constant monthly local cloud climatology from MODIS, Optical depth, Angstrom exponent, SSA from MISR. Constant asymmetry parameter.

Some regional emission analysis

- (nothing to do with CERES)
- (lots to do with the energy budget)

- What parts of the world contribute to these wedges?



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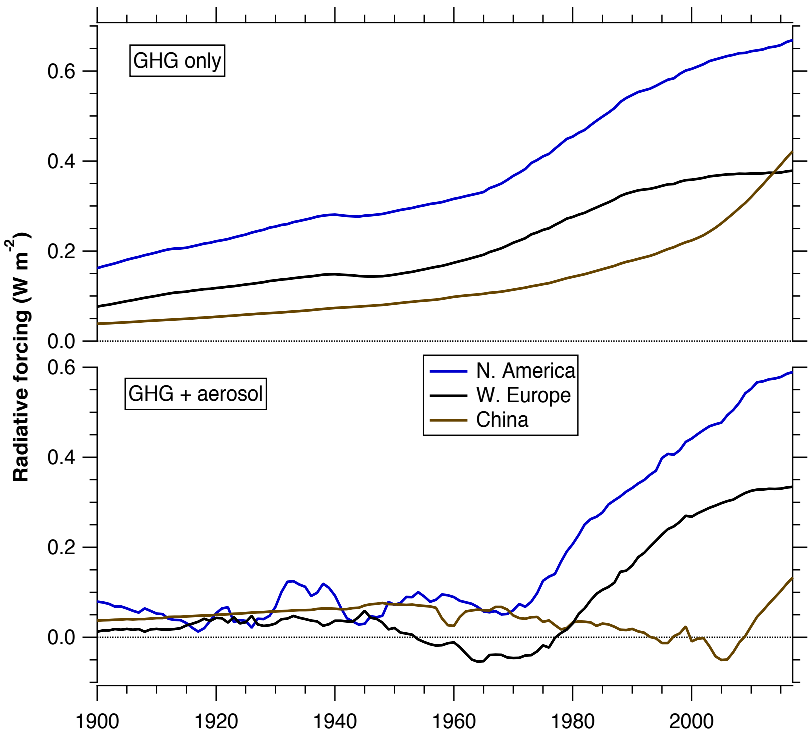
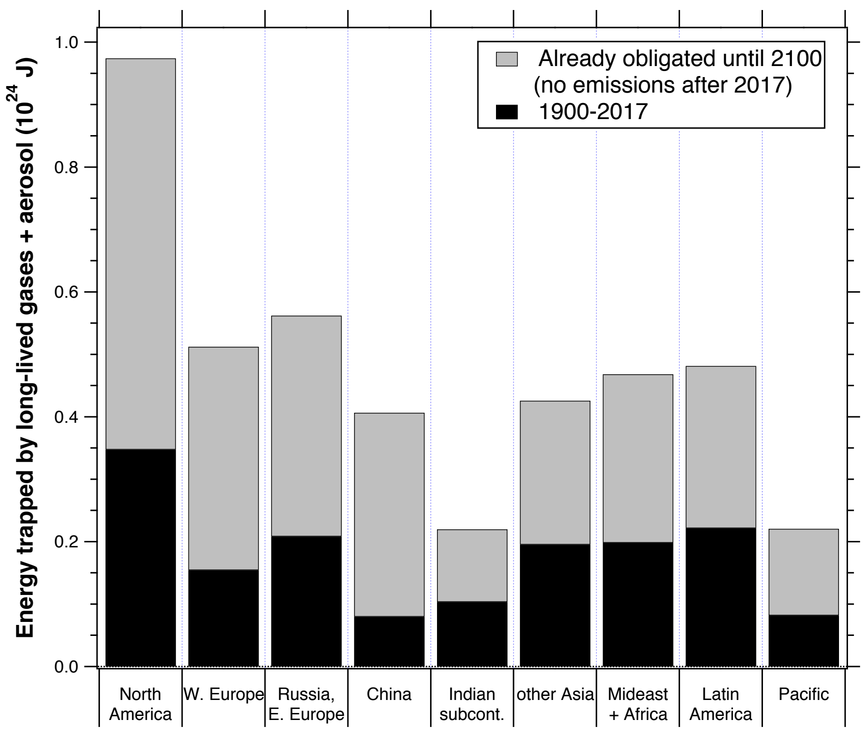


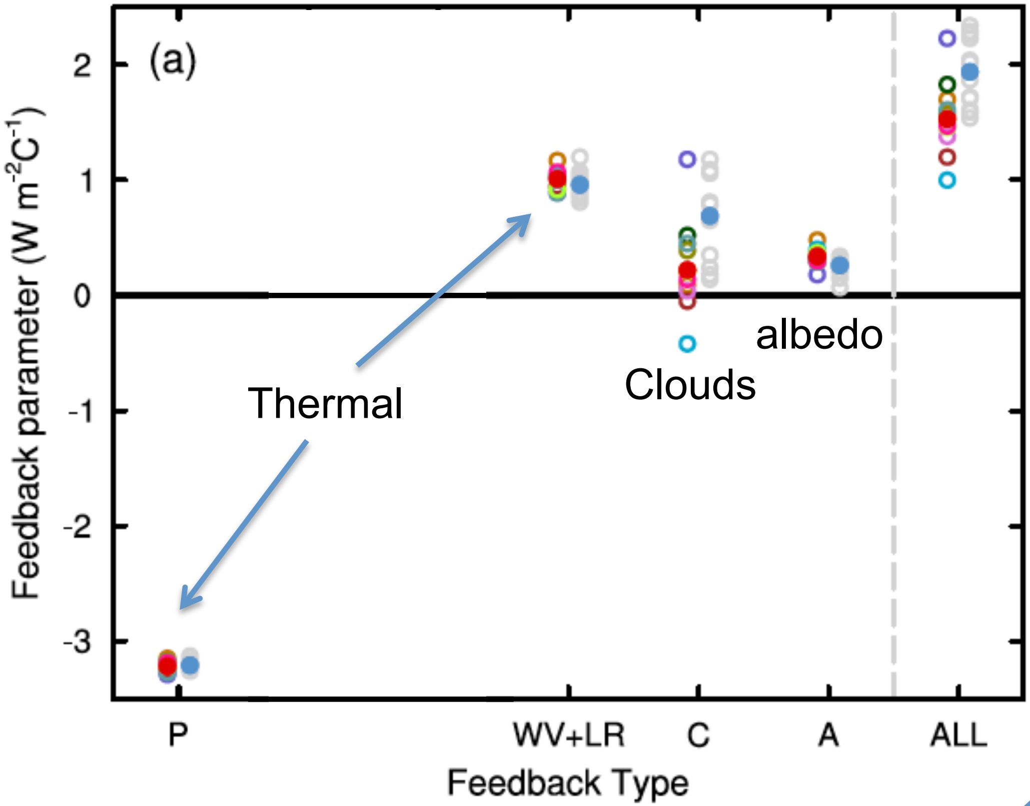


Murphy and Ravishankara, submitted

Conclusions

- The overall Earth energy budget to date does not imply a unique climate sensitivity, depending on allotting energy to *aerosol forcing* or *climate feedback*.
- Climate feedbacks (decadal) between about 0.8 to 3 W m^{-2} K^{-1} are compatible with CERES data, depending on how the data are chosen and averaged.
- Climate feedbacks (decadal) between about 0.6 to 2.5 W m^{-2} K^{-1} are compatible with energy balance, depending on recent trends in aerosol forcing.
- Long-term feedback is probably smaller (higher climate sensitivity).
- There are difficult questions in how to identify and treat internal climate variability in both the CERES or energy budget data.

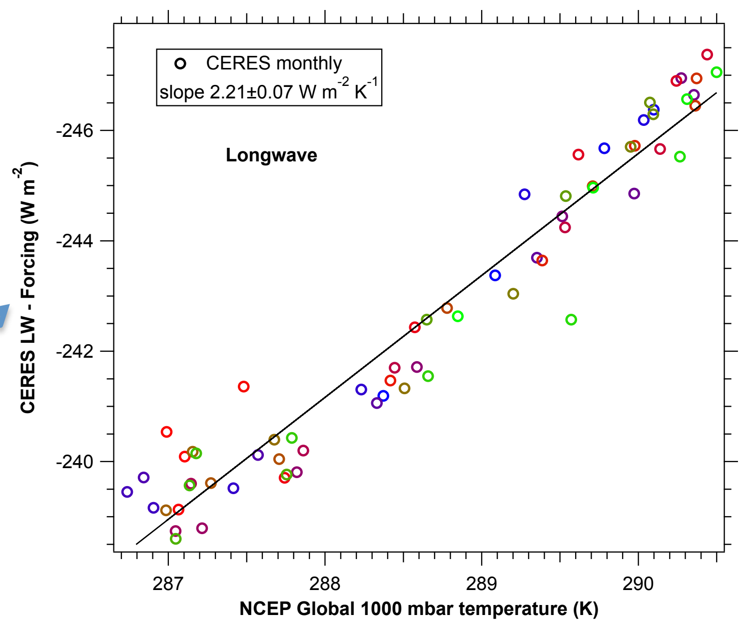
One slide: Longwave feedbacks



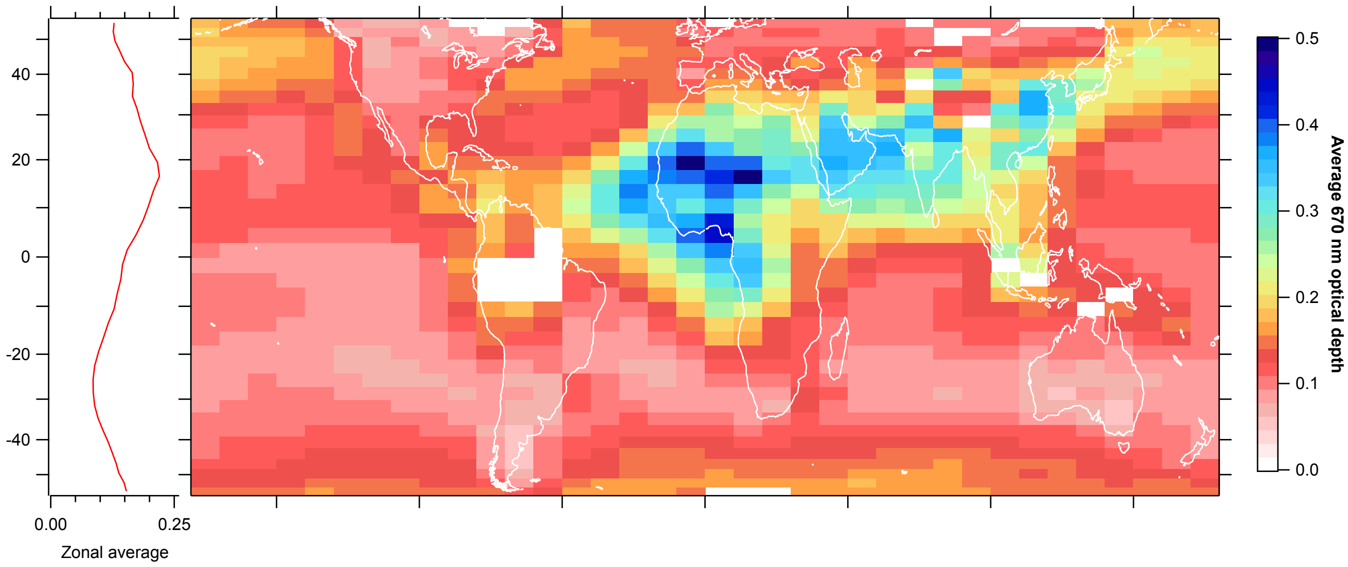
IPCC AR5 model spread

- Model feedback
  Planck: -3.2 W m^{-2} K^{-1}
  Water+lapse: 1.0 W m^{-2} K^{-1}

- CERES slope: -2.2 W m^{-2} K^{-1}
  (not exactly the same thing: e.g. clouds have IR effects)



Aerosols: a global picture



Optical depth
Annual average

MISR 2001-2012

Absolute long-term changes are daunting

Subjective: Say that ± 0.15 W m^{-2} is significant
What stability is required for the 15 years Terra has been in orbit?

- **Aerosol optical depth**: 0.005 $decade^{-1}$
- **Total energy**: (e.g. CERES): < 0.04% $decade^{-1}$
- **Cloud cover:** perhaps 0.1% $decade^{-1}$
- **Single scattering albedo:** perhaps 0.01 $decade^{-1}$

Planck feedback

$d/dT(\varepsilon\sigma T^4)$ ε = mean emissivity

$= 4\varepsilon\sigma T^3$

$= 4\varepsilon\sigma T^4/T$

= 4(Eout)/T

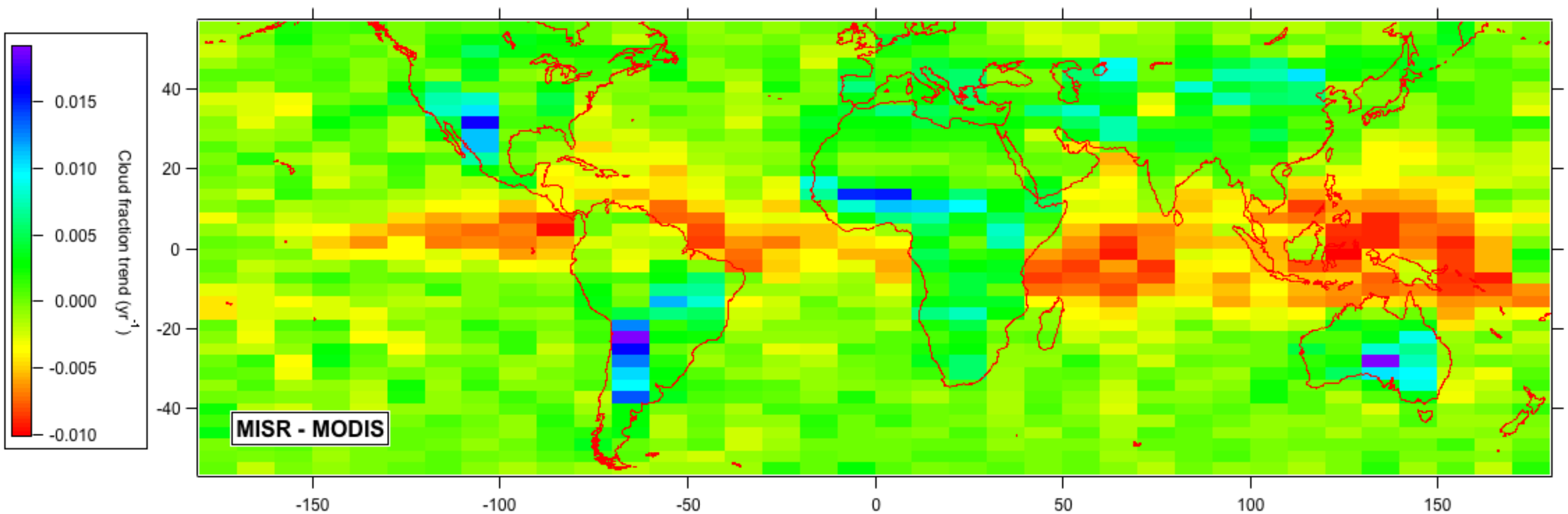
Eout / T ≈ 0.75 W m-2 K-1

Planck feedback ≈ 3 W m-2 K-1

Absolute long-term changes are daunting

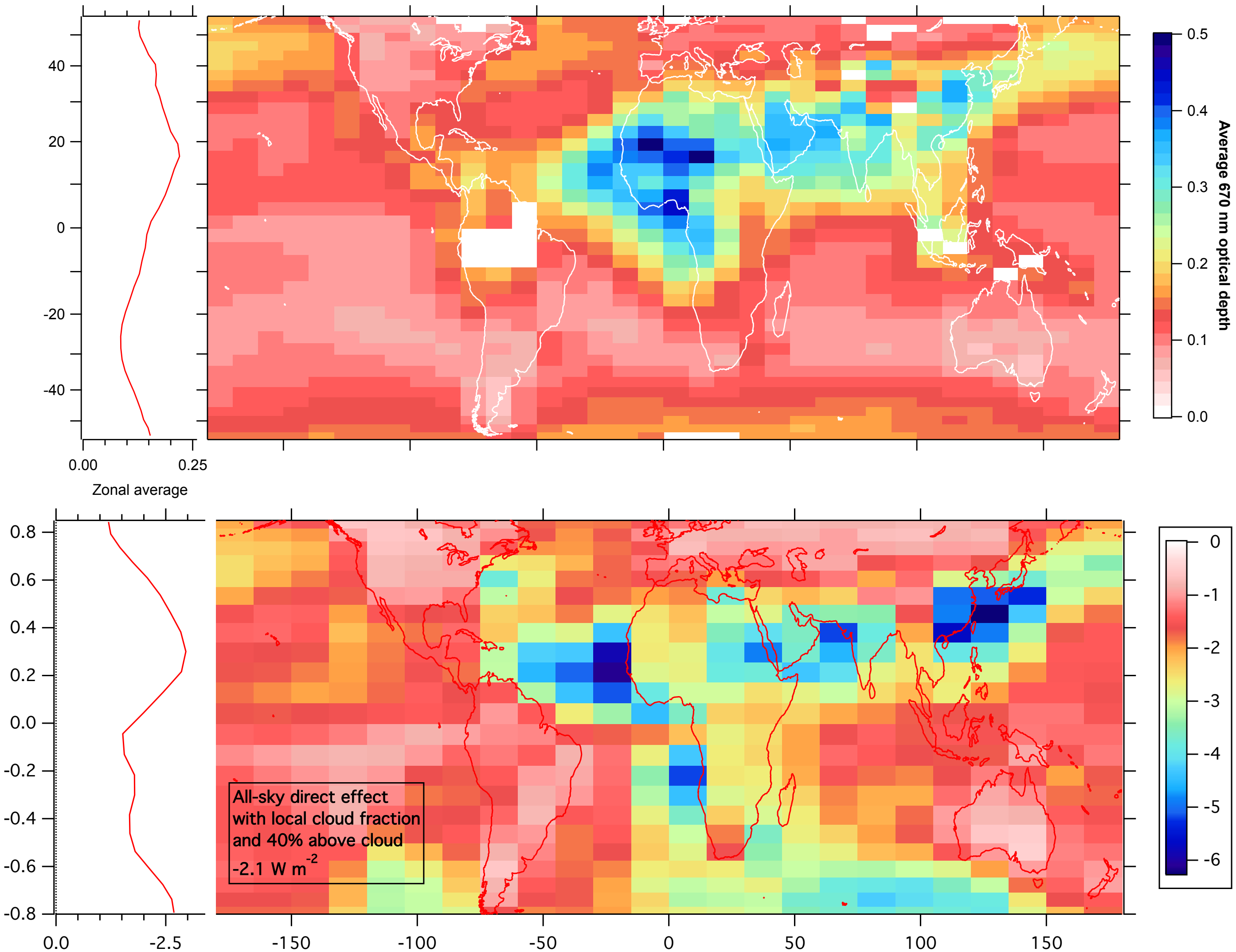
Example: many measurements depend on a cloud filter

- Relative changes in the MISR and MODIS cloud filters:
- 12% changes over the tropical oceans.



(as of 2013 download; newer data versions may help this)

Aerosols: a global picture



Optical depth
Annual average

Radiative effect
(W m^{-2})
(effect not forcing)

All-sky shortwave with constant monthly local cloud climatology from MODIS, 40% of aerosol above cloud
Optical depth, Angstrom exponent, SSA from MISR. Constant asymmetry parameter.